

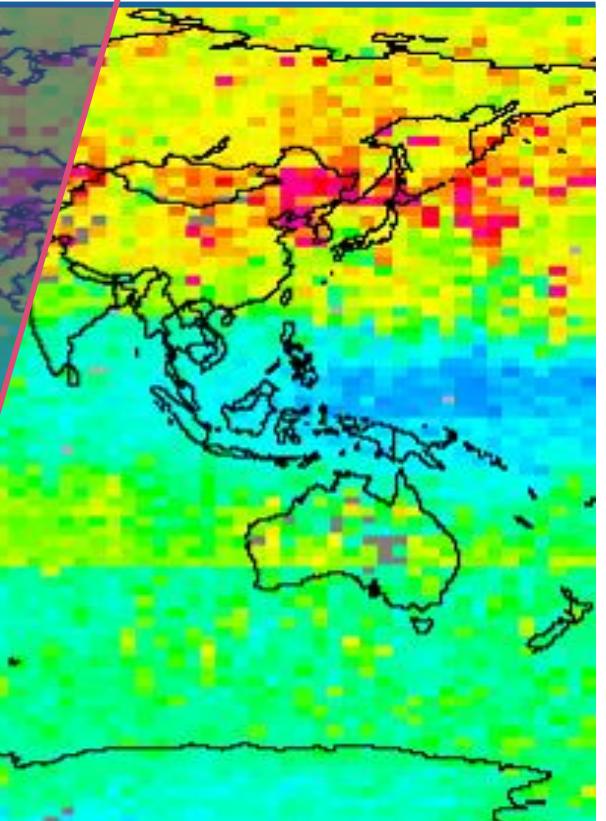


Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the
Environment*



**Attributing 2005-2010 increases in free
tropospheric ozone to rising
anthropogenic NOx emissions over
eastern Asia with the TES and OMI
sensors and the TM5 chemical transport
model**

**W.W. Verstraeten, K.F. Boersma,
J. Zörner, M.H.A. van Geel,
K.W. Bowman**

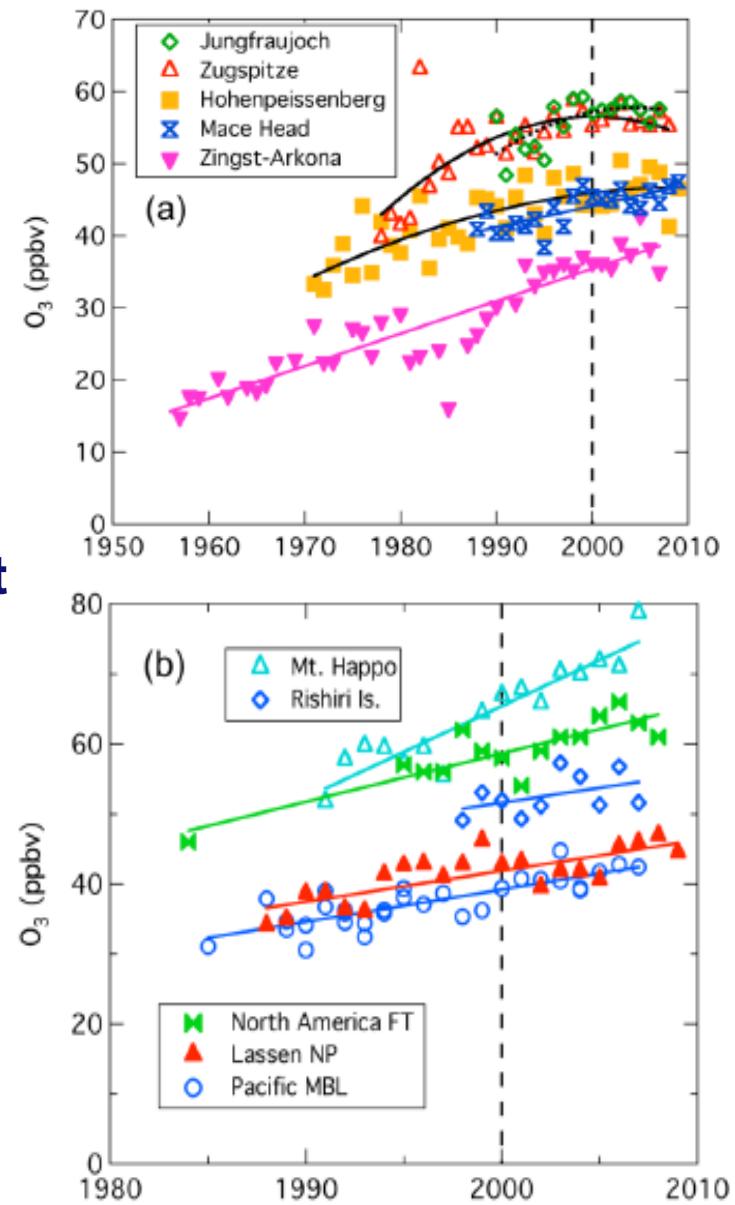


TU/e

Technische Universiteit
Eindhoven
University of Technology

Is tropospheric ozone (still) changing?

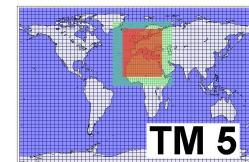
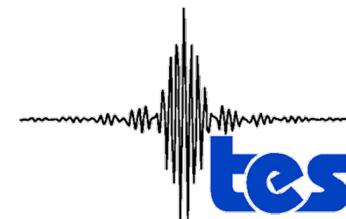
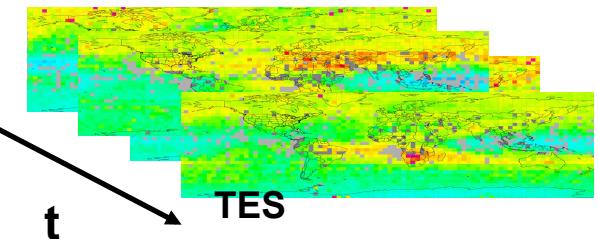
- Tropospheric ozone has likely been increasing at many background locations in the 1990s. These increases have continued mainly **over Asia** and flattened over Europe during the last decade.
- Assessment of ozone trends is difficult due to scarcity of long-term measurement sites in combination with relatively short lifetime of ozone and the meteo influence (photochemistry, stratospheric inflow).
- Applied datasets are ozone sondes, ground-based instruments, MOZAIC etc, but almost **no satellite data analysis!**



Is tropospheric ozone (still) changing?

Motivation of this study

- Can we see changes in tropospheric ozone in 2005-2010 timeframe from space?
- Is TES a good instrument to detect this?
- What is the relation between trends in ozone and trends in ozone precursors?



TES: Tropospheric Emission Spectrometer

Validation of TES tropospheric ozone with sondes

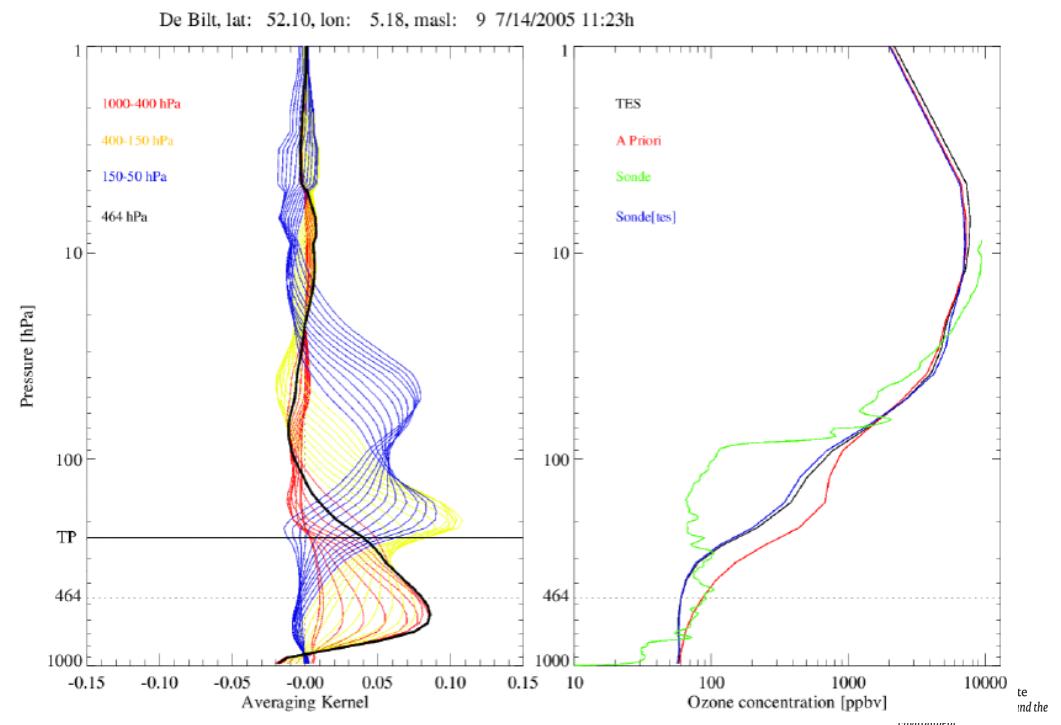
- **TES:** on board NASA EOS-Aura satellite (operational 2004-now)
- Detects infrared radiation upwelling from Earth's atmosphere
- Ozone retrieval around $9.6 \mu\text{m}$ ($3.3\text{-}15.4 \mu\text{m}$) band
- Pixel $5.3 \times 8.3 \text{ km}^2$
- Sensitive to ozone in the free troposphere
- **Sonde – TES:** temporal and spatial coincidence criteria: $\pm 300 \text{ km}$ and $\pm 9 \text{ hrs}$ (Nassar et al., 2008)
- TES version 4: 2005-2010 & WOUDC data: **4460 data pairs**
- All sonde data interpolated to a fine level pressure grid (800 levels from 1260 hPa to 0.46 hPa)
- Mapping matrix to interpolate to the 67 pressure level TES grid (from 1212 to 0.1 hPa).

Validation of TES tropospheric ozone data with sondes

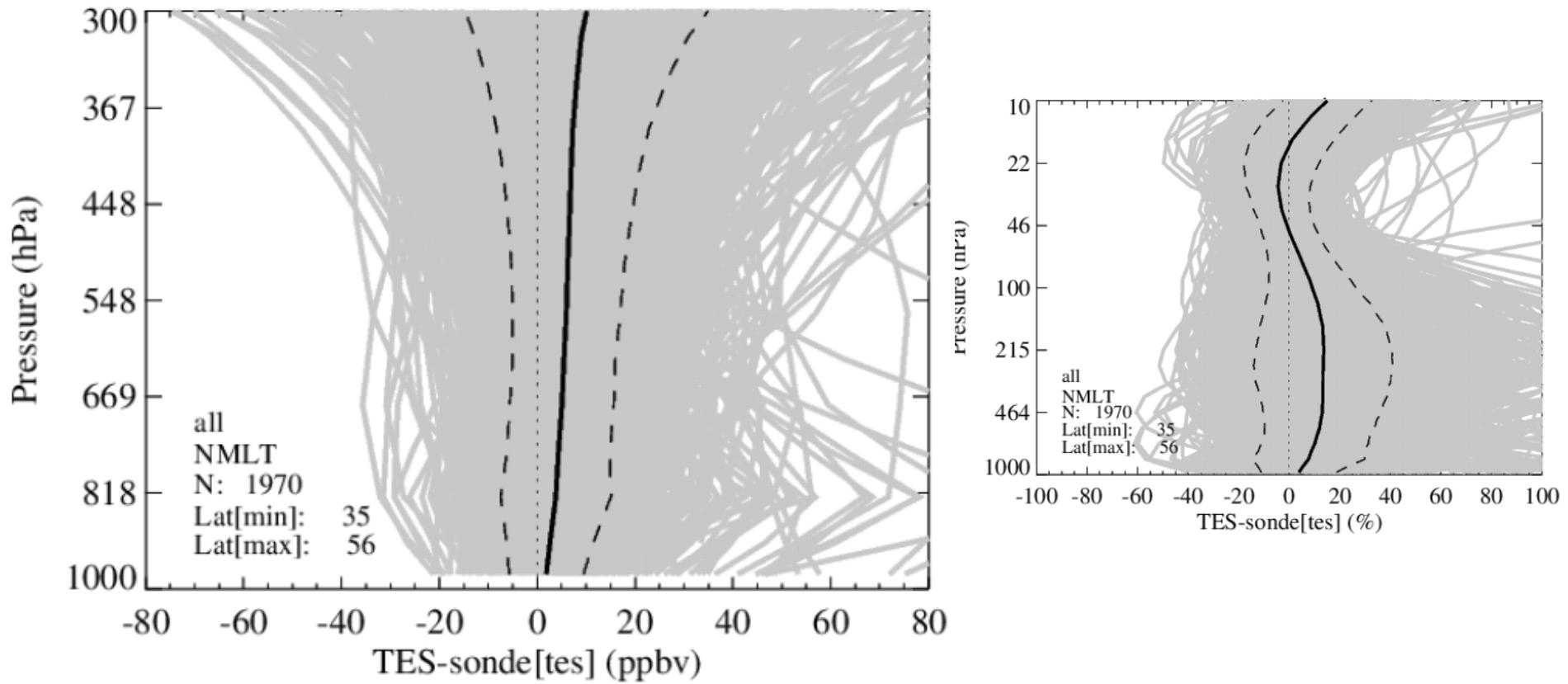
- Accounting for TES sensitivity and vertical resolution to the sonde data: applying the TES operator (TES averaging kernel & a priori constraint vector):

$$\mathbf{x}_{\text{sondeTESop}} = \mathbf{x}_{\text{prior}} + \mathbf{A}_{\text{TES}} [\mathbf{x}_{\text{sonde}} - \mathbf{x}_{\text{prior}}]$$

- This is the profile that would be retrieved from TES for the same air sampled by the sonde in the absence of other errors.

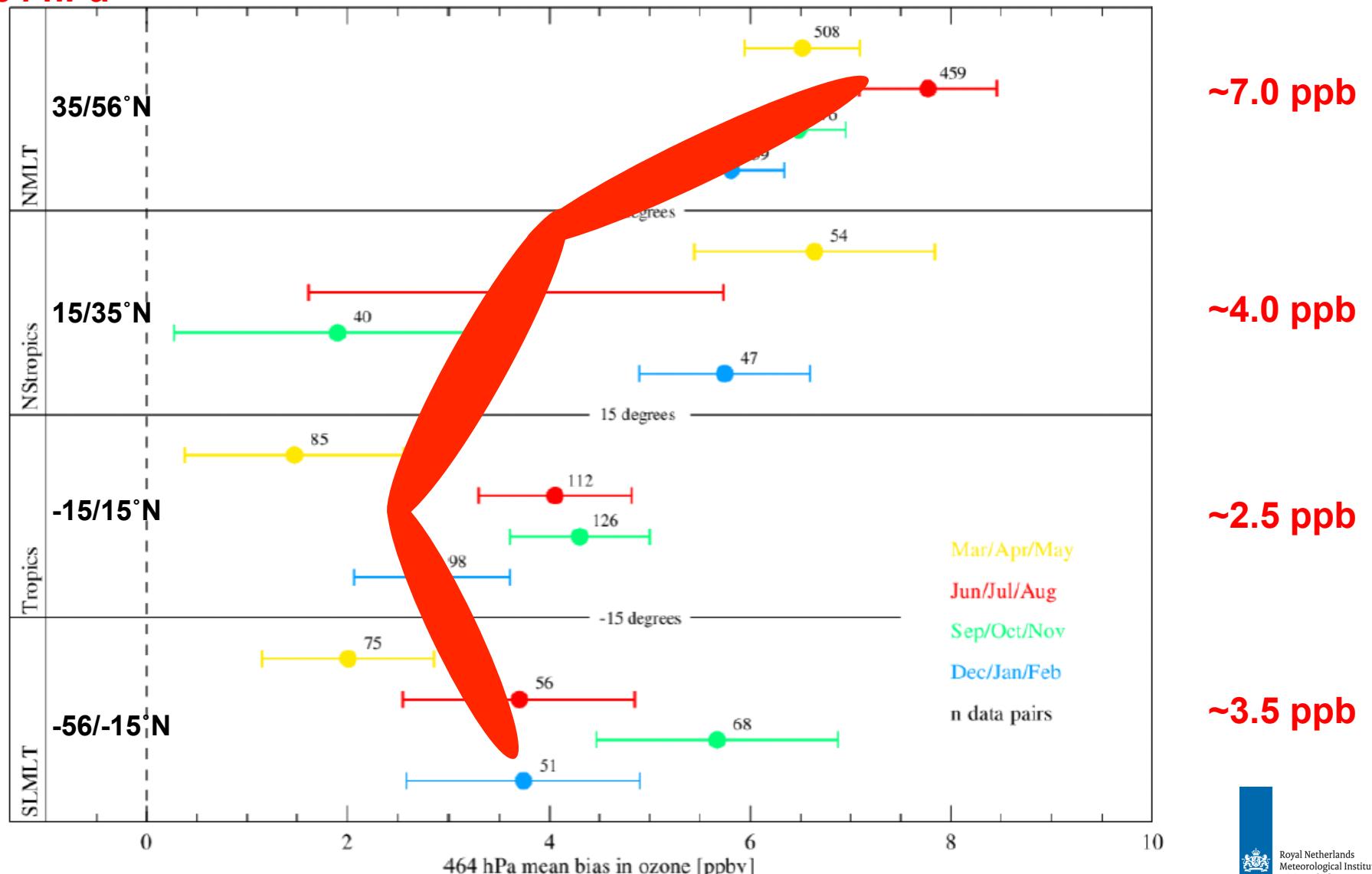


Ozone profiles of TES-Sonde difference data

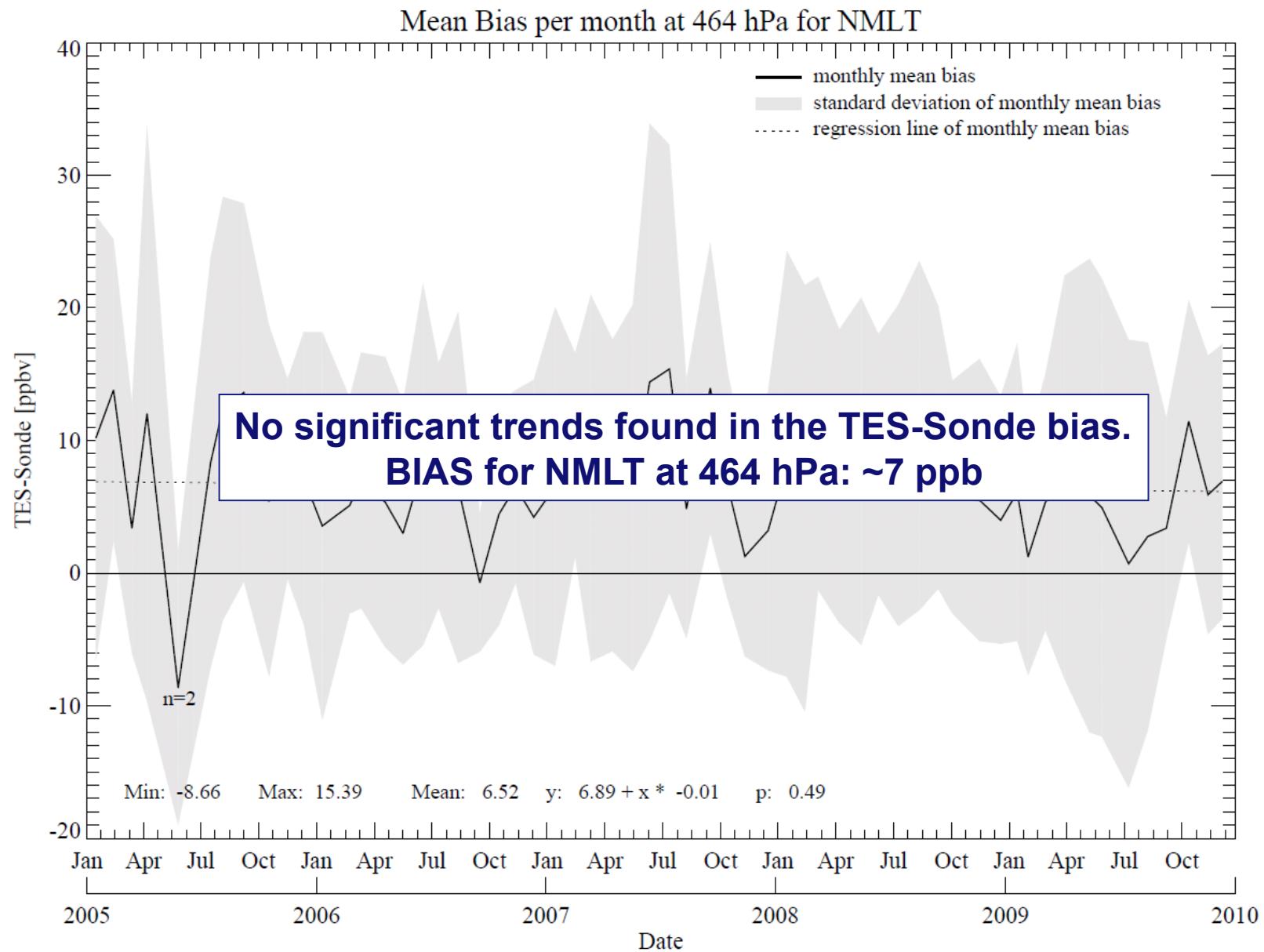


Spatial patterns in TES-sonde FTO biases

464 hPa

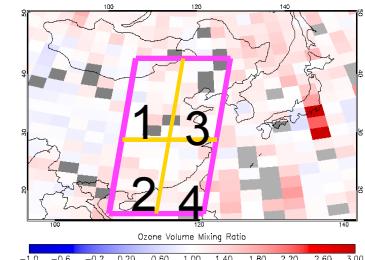


Trend in TES-Sonde ozone biases?

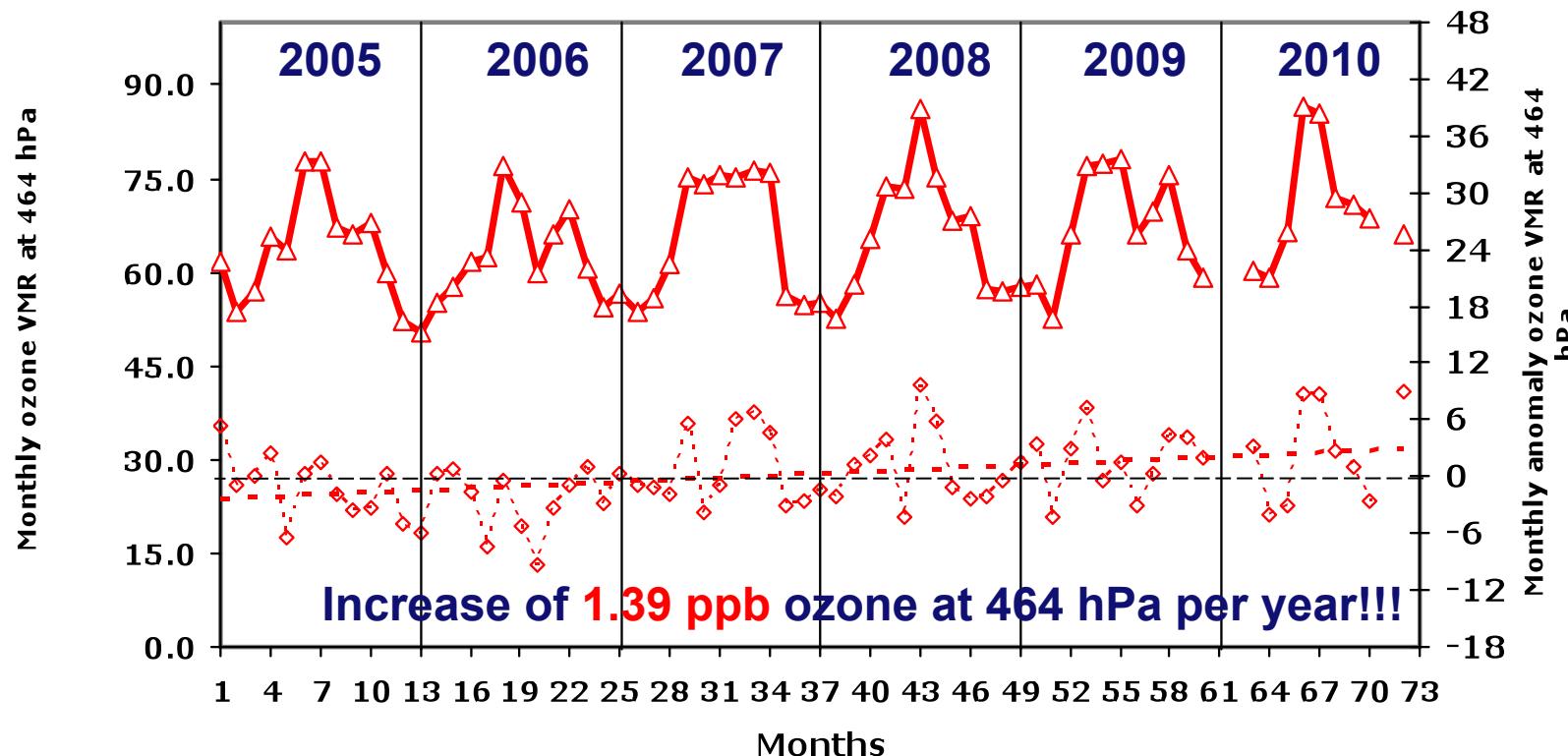


Free Tropospheric Ozone (FTO) trends

- Consequently, TES is an appropriate instrument for detecting changes and trends in tropospheric ozone!



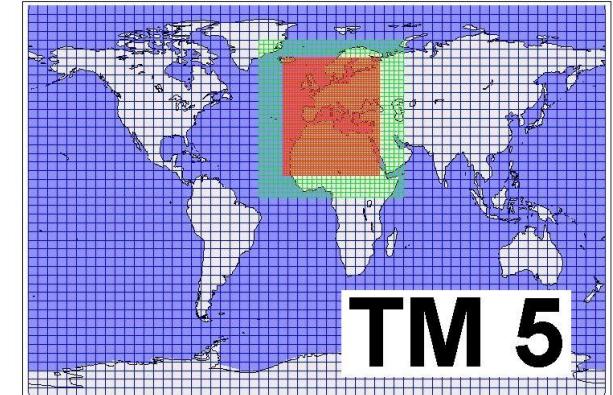
—▲— TES -·-♦- Anomaly TES -·-·- Lineair (Anomaly TES)



T

Chemical Transport Model: Tracer Model, TM5

- 34 vertical layers (surface-0.1hPa), $3^\circ \times 2^\circ$ horizontal resolution
- ECMWF meteorological fields (ERA-interim re-analysis).
- Emission inventories:
 - Anthropogenic inventories: RETRO project + REAS inventory for the Asian region
 - Lightning NOx emissions: ~5 Tg N/yr
 - Biomass burning emissions: GFEDv2
- Tropospheric chemistry: 42 species and > 60 reactions (CBM-IV)
- Reference: Huijnen et al., 2010.



Updating the anthropogenic emission inventory of TM5 using OMI NO₂ columns data

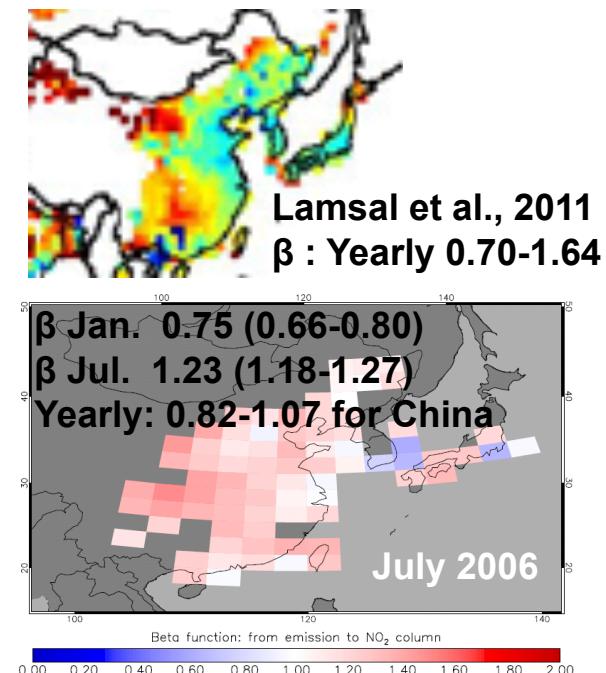
Estimating the function relating NO_x emissions to the tropospheric NO₂ columns of the CTM for 2006 as reference year (Lamsal et al, 2011):

$$\frac{\Delta E}{E} = \beta \cdot \frac{\Delta \Omega_{\text{TM5},2006}}{\Omega_{\text{TM5},2006}}$$

Using the local β sensitivity, we now update the NO_x emissions in TM5 (adapted from Lamsal et al, 2011):

- Accounting for trends in NO₂ columns relative to 2006
- Accounting for biases in emissions in the base year 2006:

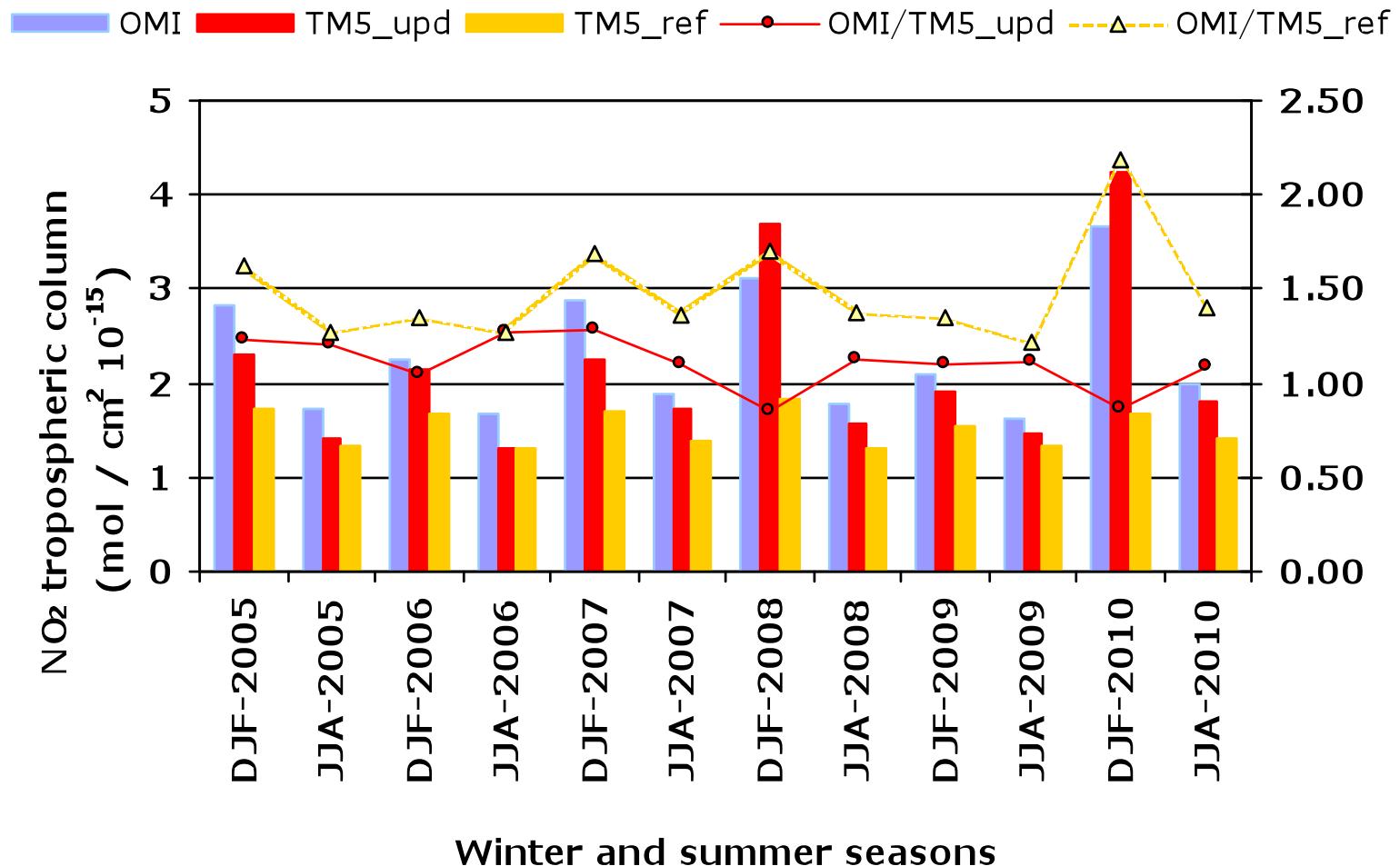
$$E_j = E_{2006} \cdot \left(1 + \beta \cdot \frac{\Omega_{\text{OMI},j} - \Omega_{\text{OMI},2006}}{\Omega_{\text{OMI},2006}} \right) \cdot \left(\frac{\Omega_{\text{OMI},2006}}{\Omega_{\text{TM5},2006}} \right)$$



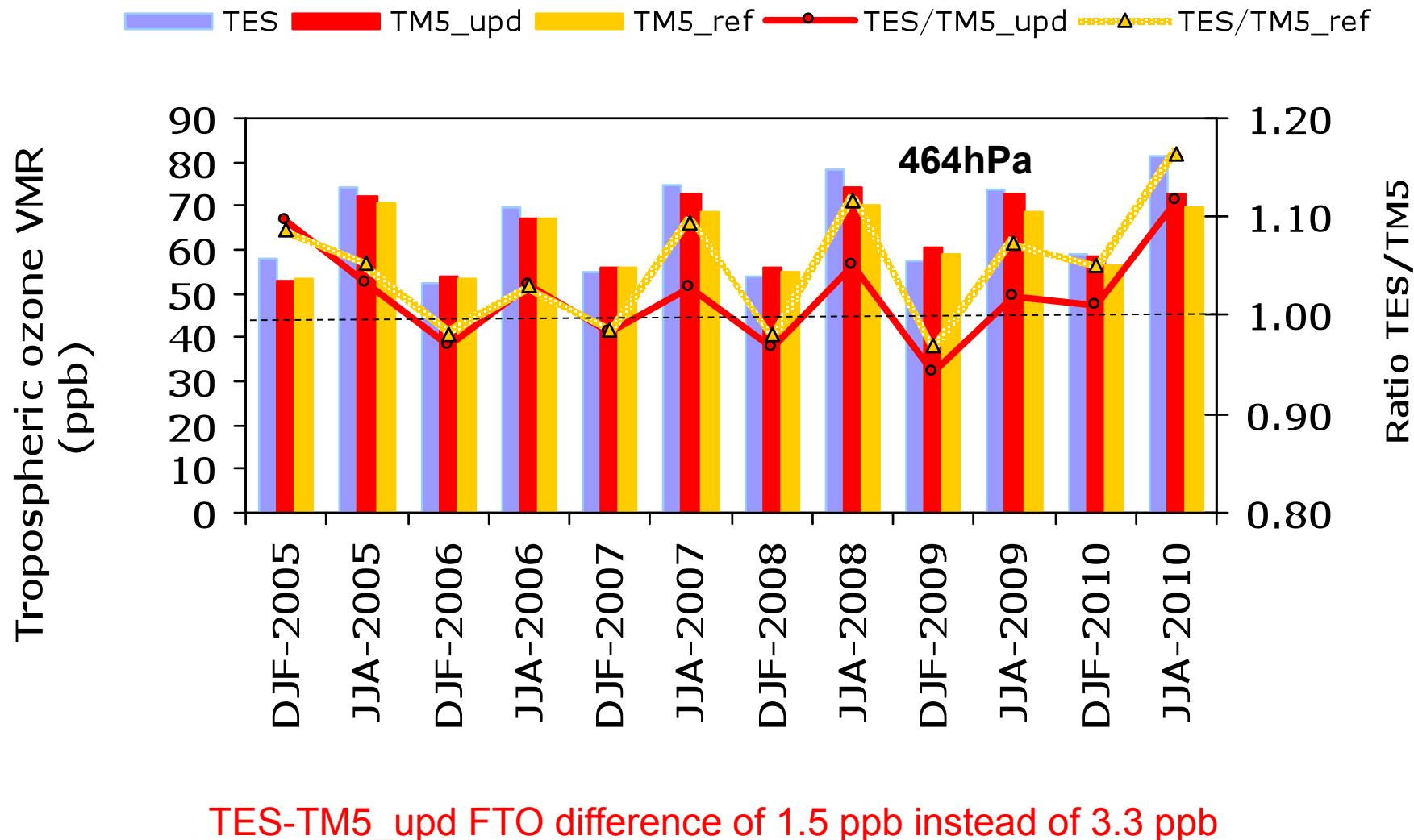
EF Jan07. 1.62 (1.34-2.74)
EF Jul07. 1.26 (1.07-1.63)
Yearly 1.38 (1.18-1.93))

OMI-TM5 tropospheric NO₂ column with and without updated emissions

OMI DOMINO v2



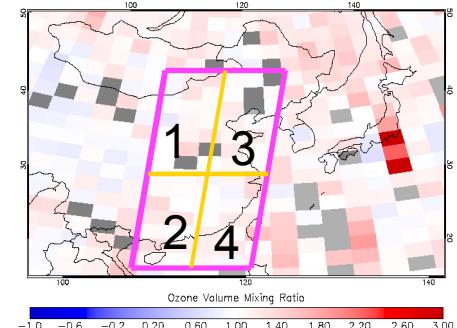
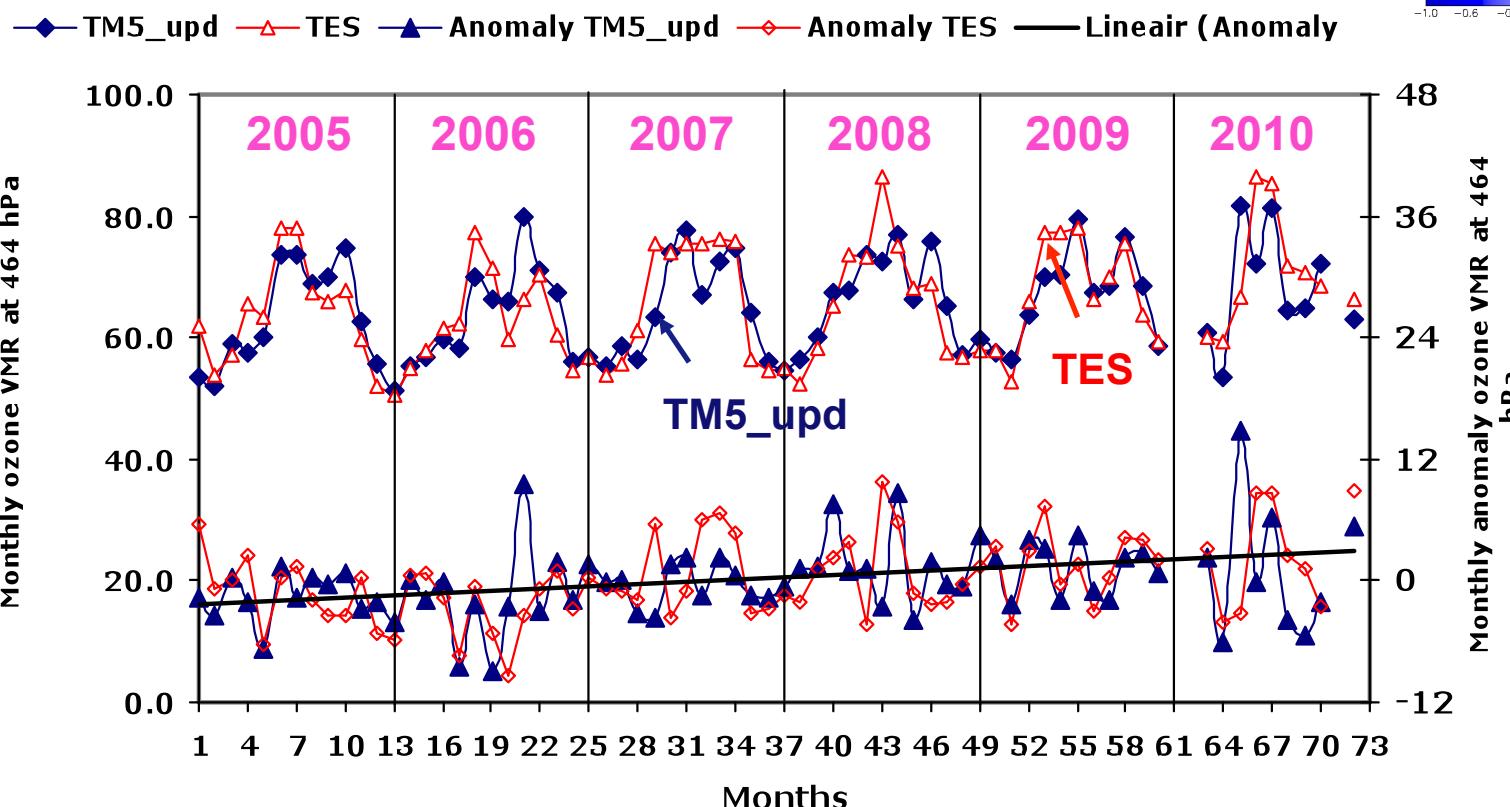
TES-TM5 tropospheric ozone at 464 hPa with and without updated emissions



Linear TES-TM5 ozone trend

ppb/y	China(0509)	China(0510)
TES:	1.06	1.39
TM5_upd:	1.09	1.28
TM5_ref:	0.68 ^{ns}	0.86 ^{ns}

Sampling bias for 2010



Conclusions

- TES – sonde FTO biases of version 4 are ~5-6 ppb
- The TES – sonde free tropospheric ozone biases show no trends in time
- Over East China a rapid FTO trend increase is observed of 1.39 ppb/yr over the period 2005-2010
- Updating the anthropogenic emissions in the TM5 model using time series of OMI tropospheric NO₂ columns explains observed FTO trend of TES: 0.86 ppb/yr against 1.28 ppb/yr
- Without the update in the NO_x emissions, TM5 is not able to reproduce the significant positive trend of FTO
- The trend suggests that ~40% of the FTO increase over China is home made by increasing anthropogenic emissions

Thank you for your attention!



Questions?
Remarks?
Comments?
Clarifications?
Discussions?
Hungry?!